Simulations of an Energetic Particle Instrument for Jupiter

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Abstract

Scheduled for a 2011 launch, the JUNO spacecraft will begin a 5 year cruise en route to Jupiter. Once at Jupiter, the spacecraft will perform 33 orbits over the course of a scheduled 1 year mission that will take it through the Jovian aurora. The energetic electron spectrum near the poles is expected to be intense and very hard. We use GEANT4 to optimize the design of the instrument, to quantify the shielding composition and thickness, and to model the expected primary and secondary particle environment in and near the solid state detectors and the micro-channel plate.

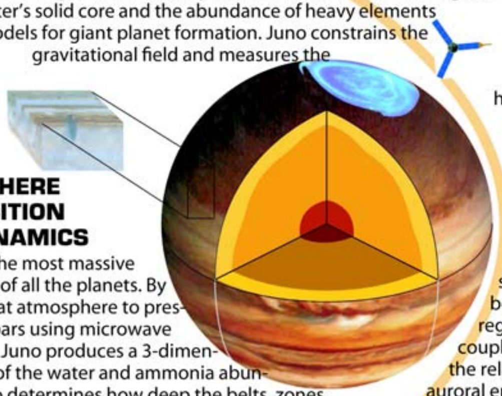
Probing Jupiter to Discover Our Origin

GOALS AND OBJECTIVES

"The giant planet story is the story of the solar system."* Juno's goal is to understand the origin and evolution of Jupiter. As the archetype of giant planets, Jupiter can provide the knowledge we need to understand the origin of our own solar system and the planetary systems being discovered around other stars. Juno's investigation focuses on four themes: Origin, Interior Structure, Atmospheric Composition and Dynamics, and the Polar Magnetosphere.

ORIGIN

No other object in the solar system can tell us more about the origin of planets than Jupiter. The mass of Jupiter's solid core and the abundance of heavy elements in the atmosphere discriminate among models for giant planet formation. Juno constrains the core mass by mapping the gravitational field and measures the global abundances of oxygen and nitrogen—the two uncertain heavy elements—through microwave observations of water and ammonia.



ATMOSPHERE COMPOSITION AND DYNAMICS

Jupiter has the most massive atmosphere of all the planets. By sounding that atmosphere to pressures >100 bars using microwave frequencies, Juno produces a 3-dimensional map of the water and ammonia abundances. Juno determines how deep the belts, zones, Great Red Spot, and other features penetrate, thereby answering the most fundamental question about Jovian atmospheric dynamics. The microwave observations also characterize the clouds, winds, and temperatures beneath the visible cloud layers.

POLAR MAGNETOSPHERE

Jupiter's magnetosphere is the largest structure in the solar system. Juno provides the first and best opportunity to explore the polar regions of this magnetosphere and its coupling to the atmosphere, establishing the relationship between remotely sensed auroral emissions and in situ plasmas, fields, waves, and radio emissions. These measurements determine the location and nature of the current systems, acceleration processes, and the impedance that limits momentum transfer, characterizing the electrodynamic coupling of Jupiter with its magnetosphere and satellites.

INTERIOR STRUCTURE

The record of Jupiter's origin and early evolution lies hidden deep within the planet's massive interior. Juno reveals this record by mapping the gravitational and magnetic fields with sufficient resolution to constrain Jupiter's interior structure, the origin of the magnetic field, the core, and the nature of deep convection. Juno's determination of the water abundance helps determine Jupiter's interior structure by constraining the total mass of heavy elements in the outer envelope.

MISSION OVERVIEW

Using a spinning, solar-powered spacecraft, Juno makes global maps of the gravity, magnetic fields, and atmospheric composition of Jupiter from a unique polar orbit with a close perijove. Juno carries precise, high-sensitivity radiometers, magnetometers, and gravity science systems. Juno's 32 orbits extensively sample Jupiter's full range of latitudes and longitudes. From its polar perspective Juno combines in situ and remote sensing observations to explore the polar magnetosphere and determine what drives Jupiter's remarkable auroras. Without landers, probes, or returned samples, the mission has extremely low risk.

*(Quote from National Academy Solar System Exploration Decadal Survey, 2002)

Scientific Instruments

I. Atmospheric Structure
  - Microwave Radiometer (MWR)
  - Jovian Infrared Auroral Mapper (JIRAM)

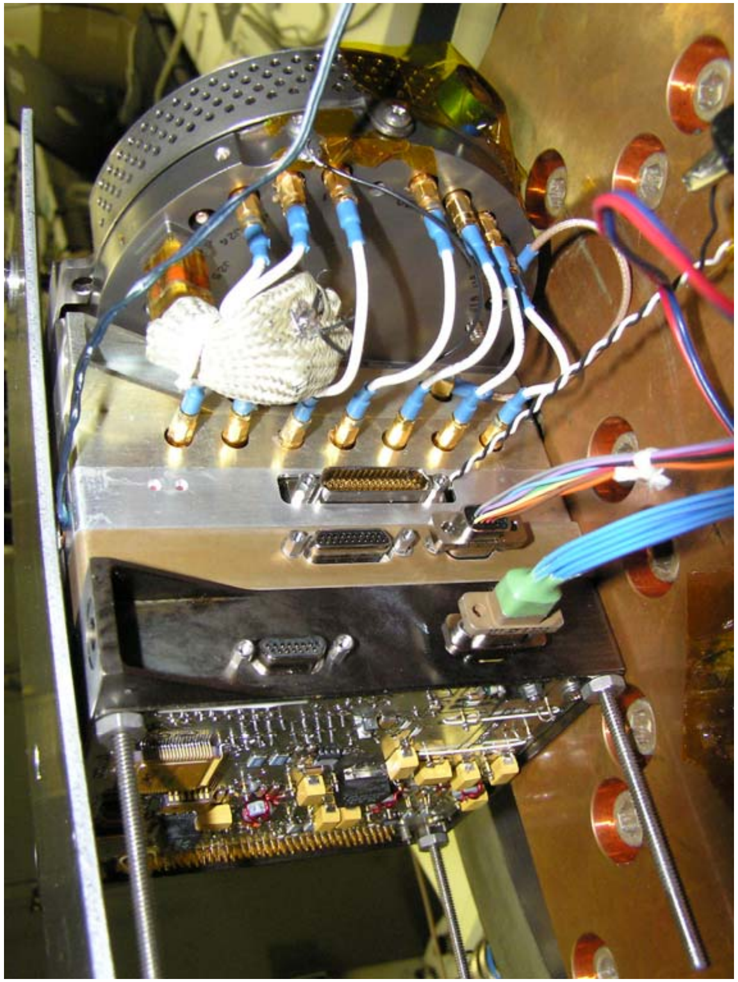
II. Magnetic Field Investigation
  - Flux Gate Magnetometer and Scalar Helium Magnetometer
  - Advanced Stellar Compass (ASC)

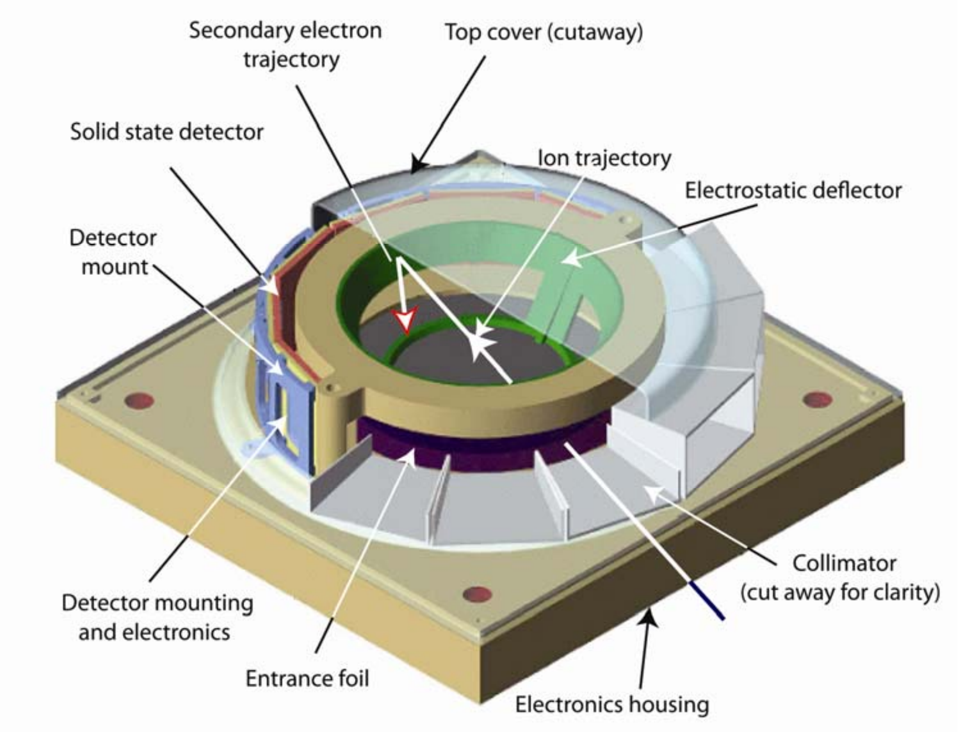
III. Polar Magnetosphere Suite
  - Jovian Auroral Distribution Experiment (JADE)
  - Jupiter Energetic-Particles Detector Instrument (JEDI)
  - Radio and Plasma Wave Sensor (WAVES)
  - Jovian Infrared Auroral Mapper (JIRAM)

IV. Interior Structure
  - Gravity Science Experiment

V. Jupiter Polar Context Imaging
  - JunoCAM

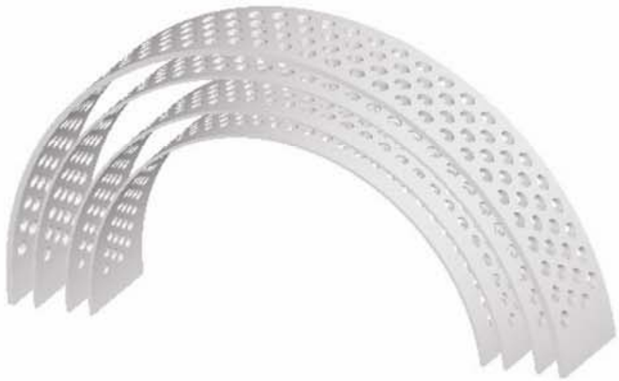
The JEDI Instrument



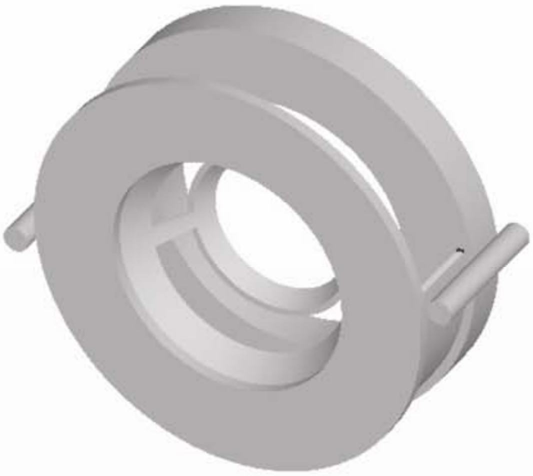


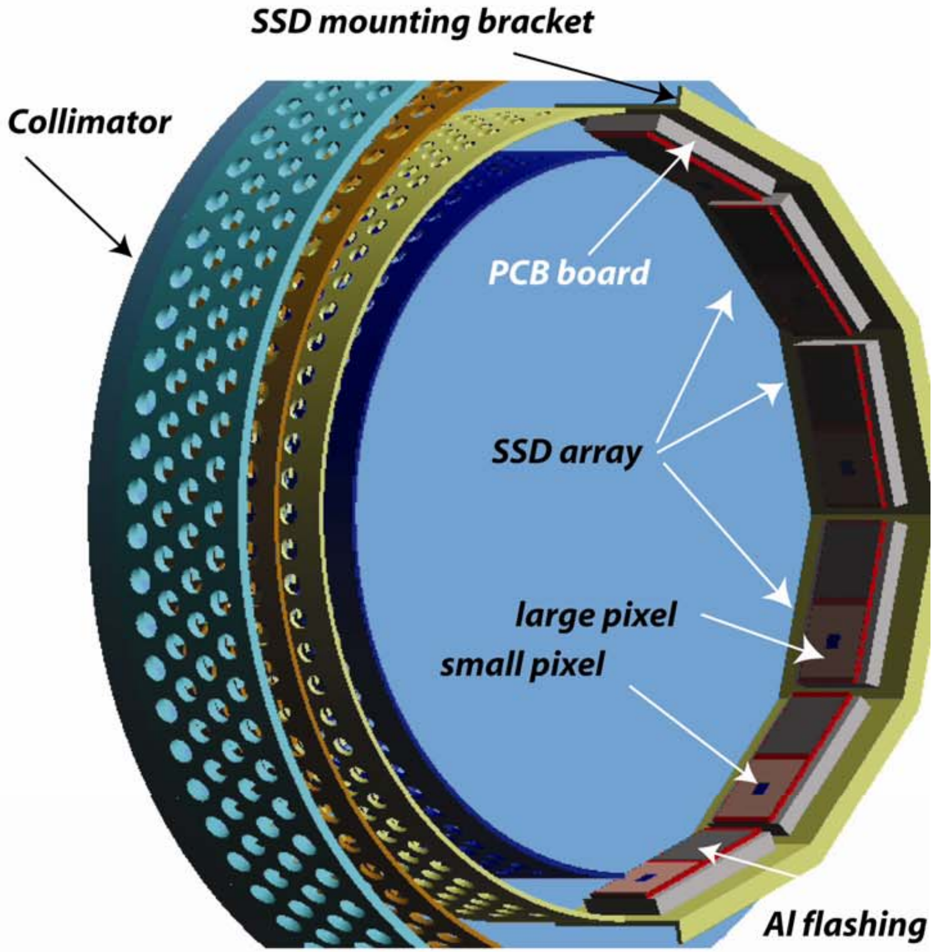
GEANT4 model of JEDI

The JEDI collimator

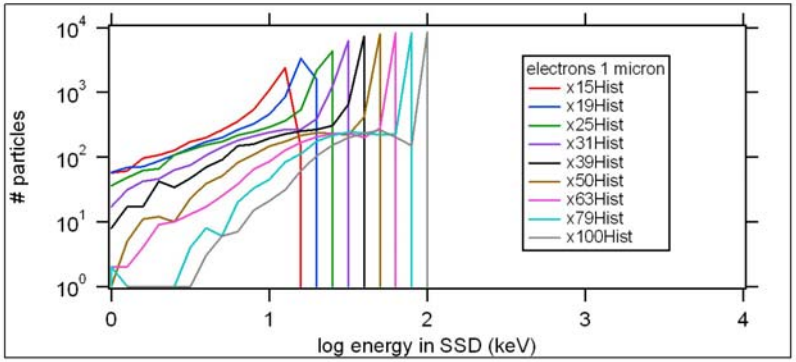


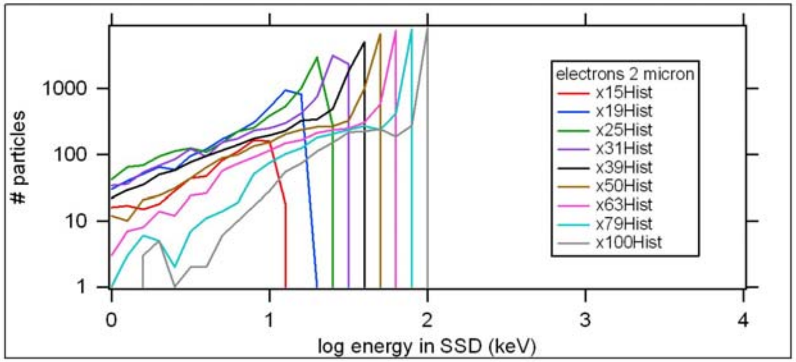
The JEDI MCP high voltage cup

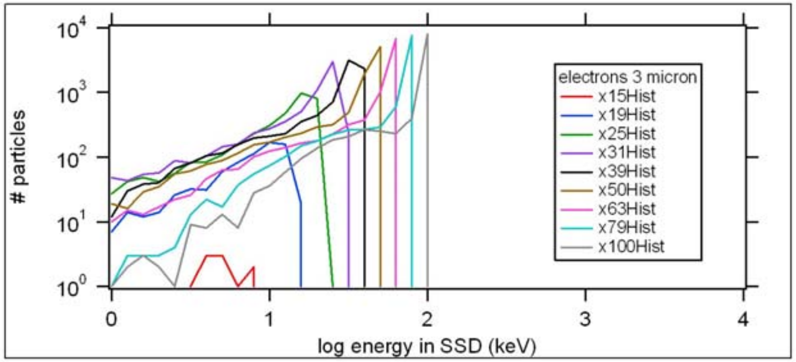




Flashing Thickness Simulations





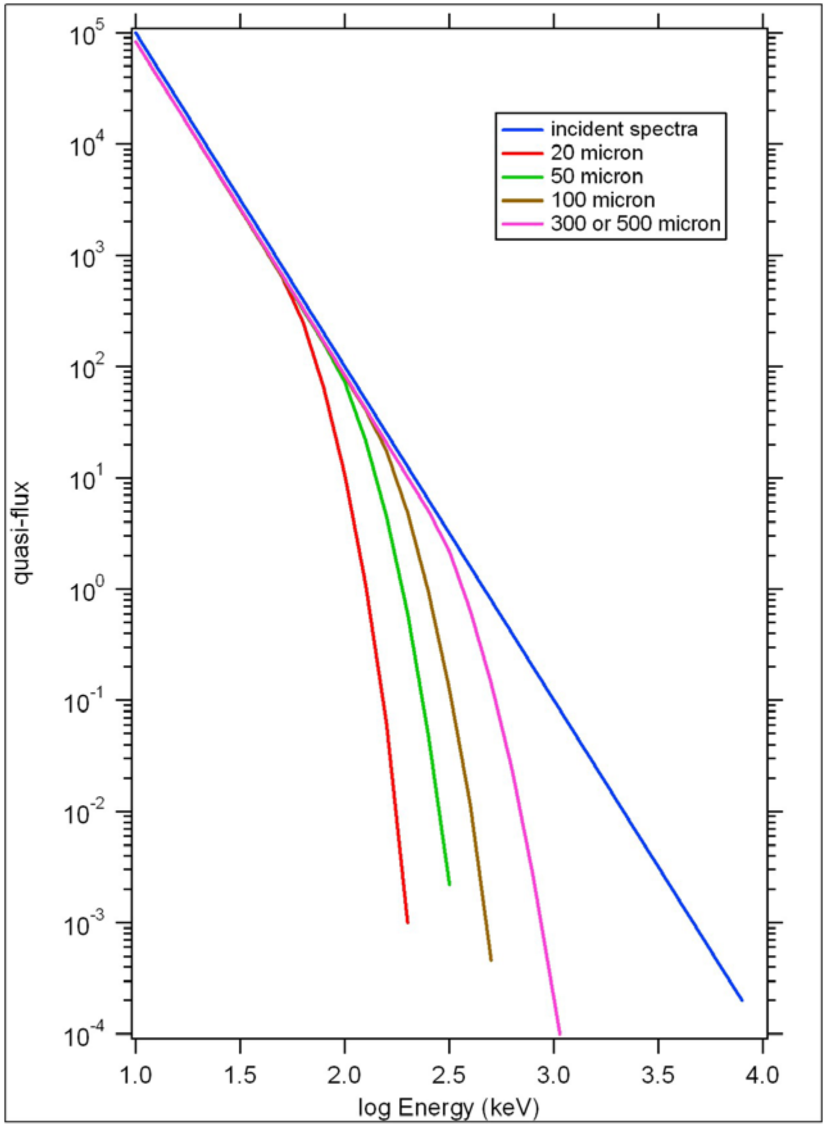


I created a very simple simulation with a 1, 2, and 3 micron Al flashing in front of a SSD. Ran a series of mono-energetic beams into the model. Only electrons and protons were used.

Results:

- The 1 micron flashing
  - 15 keV e- deposit 10 keV is SSD at 20% level
  - 125 keV protons deposit 10 keV at 20% level
- 2 micron flashing
  - 15 keV e- deposit 10 keV at 1% level
  - 20 keV e- deposit 11 keV at 10% level
  - protons below ~230 keV are kept out.
  - 240 keV protons deliver ~30 keV @ 20%
- 3 micron flashing
  - too severe
  - e- begin at 1% level @ 25 keV
  - 400 keV protons deposit 100 keV @ ~100%

GEANT4 in development



Thin vs. thick SSD simulations

Very simple SSD simulation to determine what, if any, benefit results from using a very thin detector vs. a thicker (~500 micron) detector.

Only e- used in these simulations

Power law energy spectra (GPS) into model

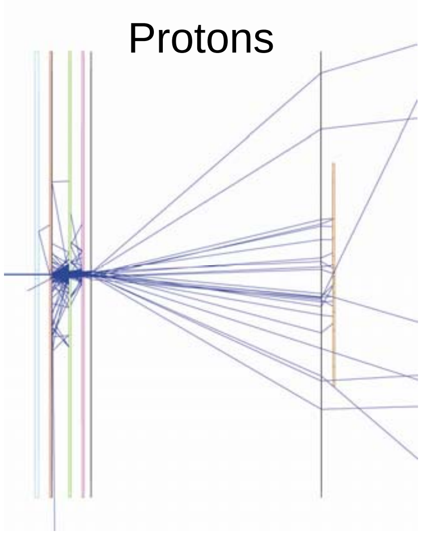
30 keV threshold on SSD

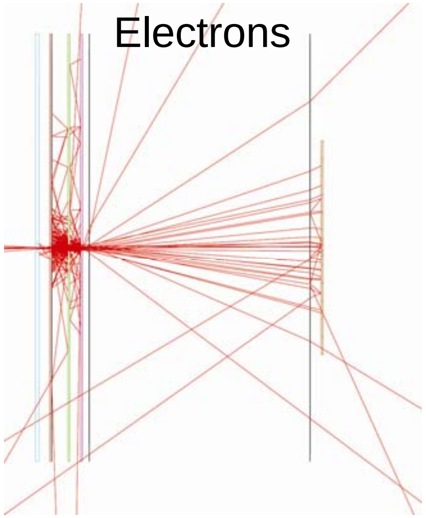
20, 50, 100, and 300 micron detectors

Results:

Thin detectors actually hurt the observations, the thick detector was selected

GEANT4 in development


Protons


Electrons

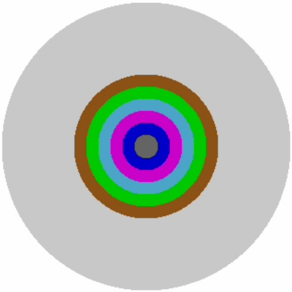
This simulation consists of four collimation surfaces with a single hole in each surface. The hole size is the same as used on EPS.

It has a foil right after the second collimation plate. Al-poly-Al

After the last plate there are two foils C-poly-C that are separated by 6 cm.

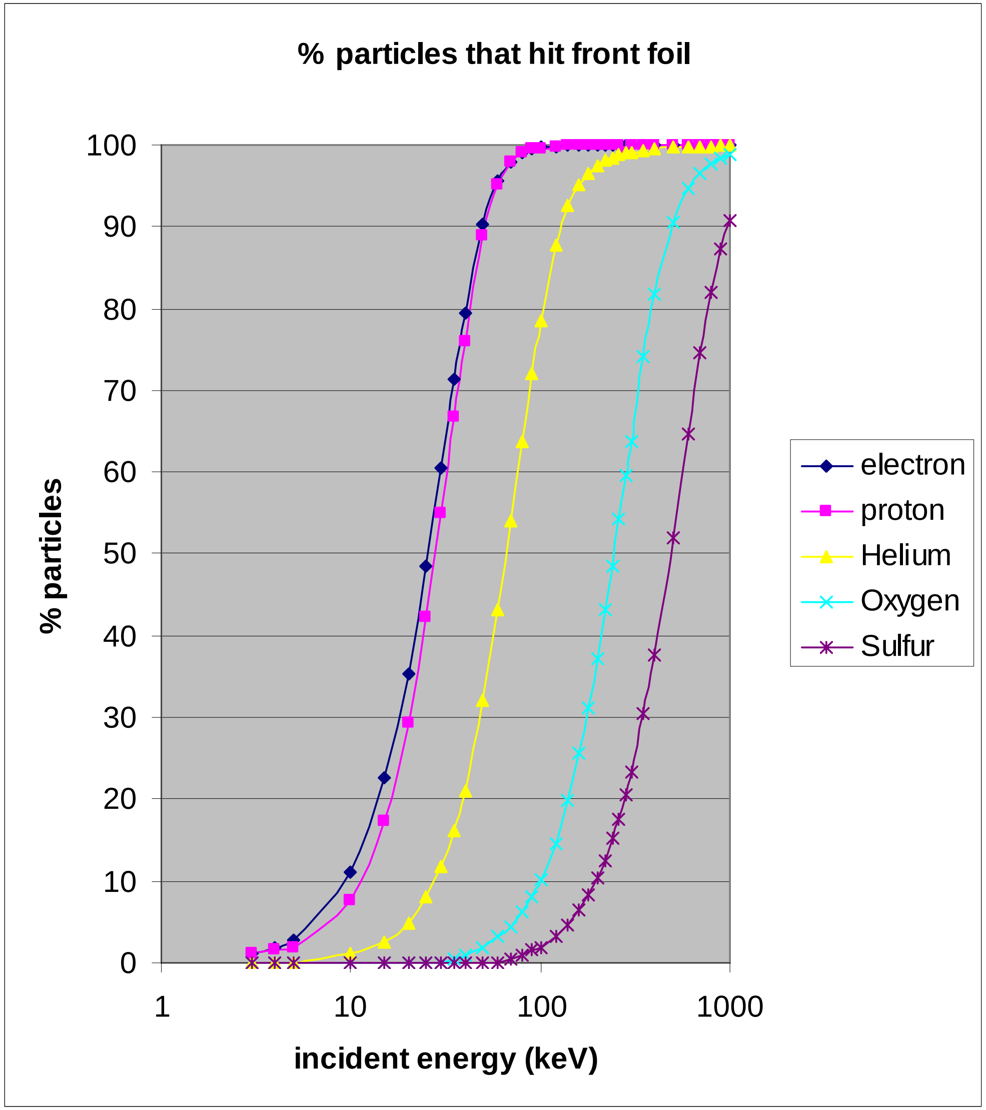
Following the final foil there is a SSD made out of concentric circular disks 500 microns thick and 0.5 cm in size. These SSDs map out the final angular distribution at the SSD.

For this round of simulations
I used a pencil beam so if there
Was not a foil in the collimator
100% of the particles would hit
The start foil



SSD disks behind very large foil

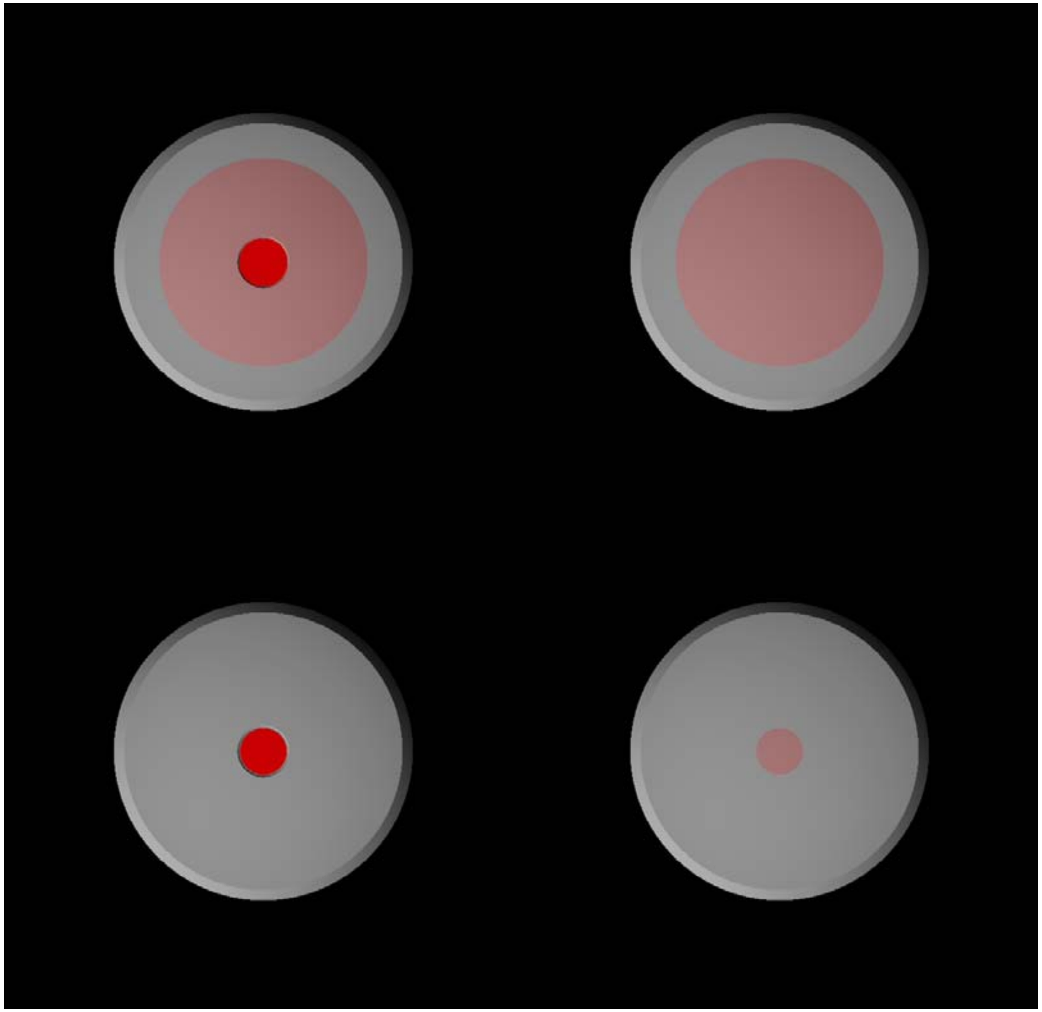
GEANT4 in development



These curves show the percentage of incident particles that strike the start foil

GEANT4 in development

Foreground/Background small/large pixel reality check

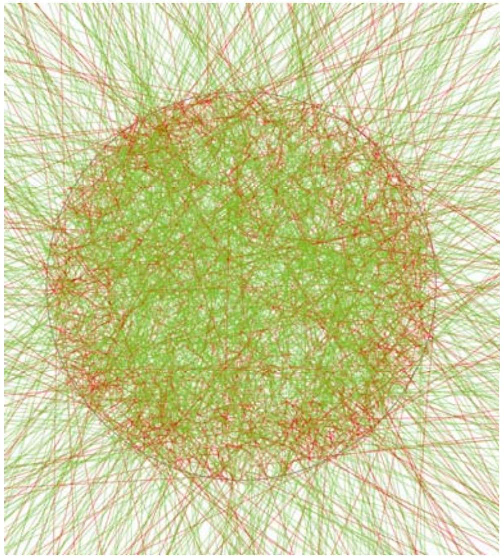


4 spherical balls with small hole in 2 of them. Large SSD in 2, small SSD in other two. A side view of the large SSD with the hole shows a cut in the other dimension.

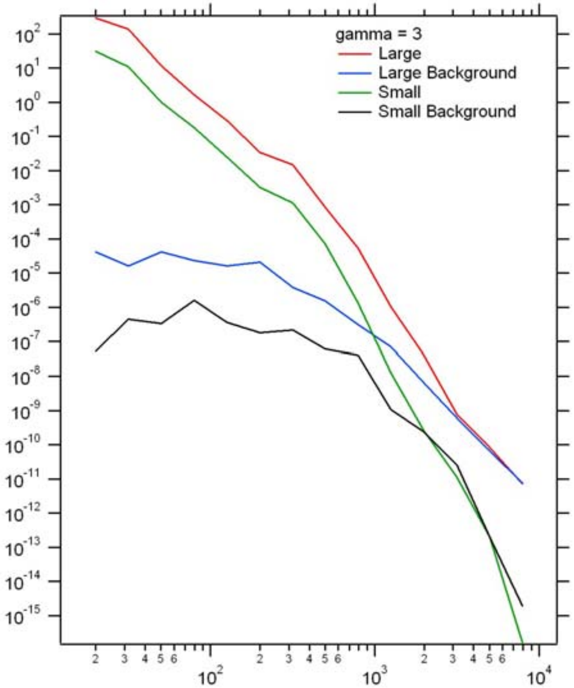
The SSD is 500 microns, similar to the EPS simulations I have been running.

The spherical shell is just a bit larger than the SSD inside.

I then followed the standard technique where I surrounded the model in a spherical surface, cosine angular distribution, log spaced monoEnergetic runs, etc…

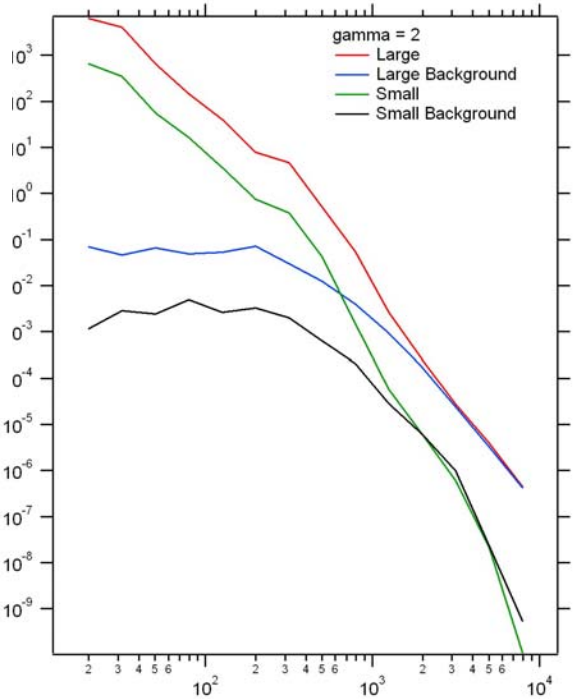


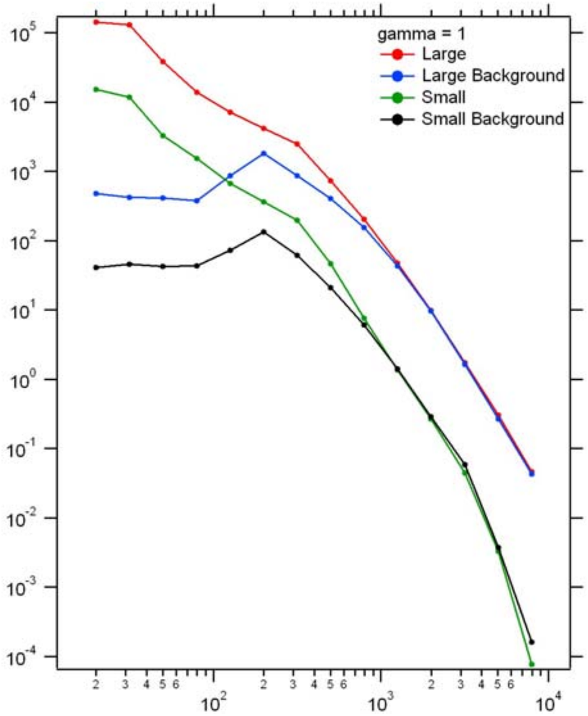
GEANT4 in development



Foreground/Background small/large pixel reality check cont.

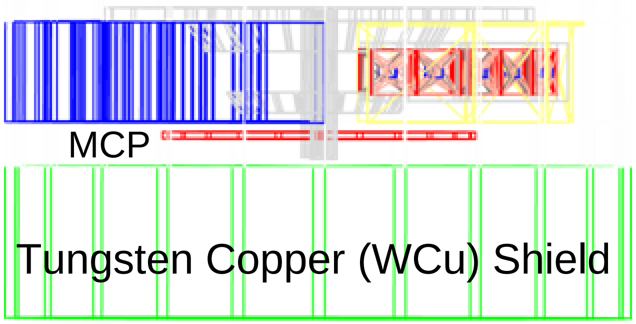
Exactly what you would expect. Small detector scales with large detector by a geometrical factor, and the foreground and background merge at an energy associated with the input spectra.

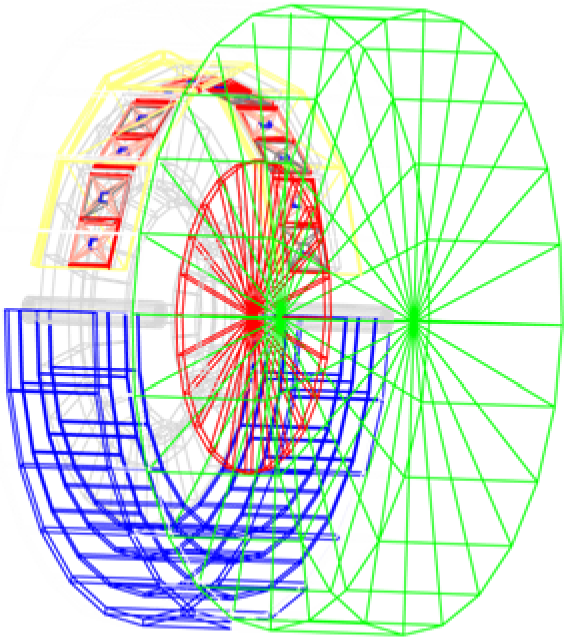


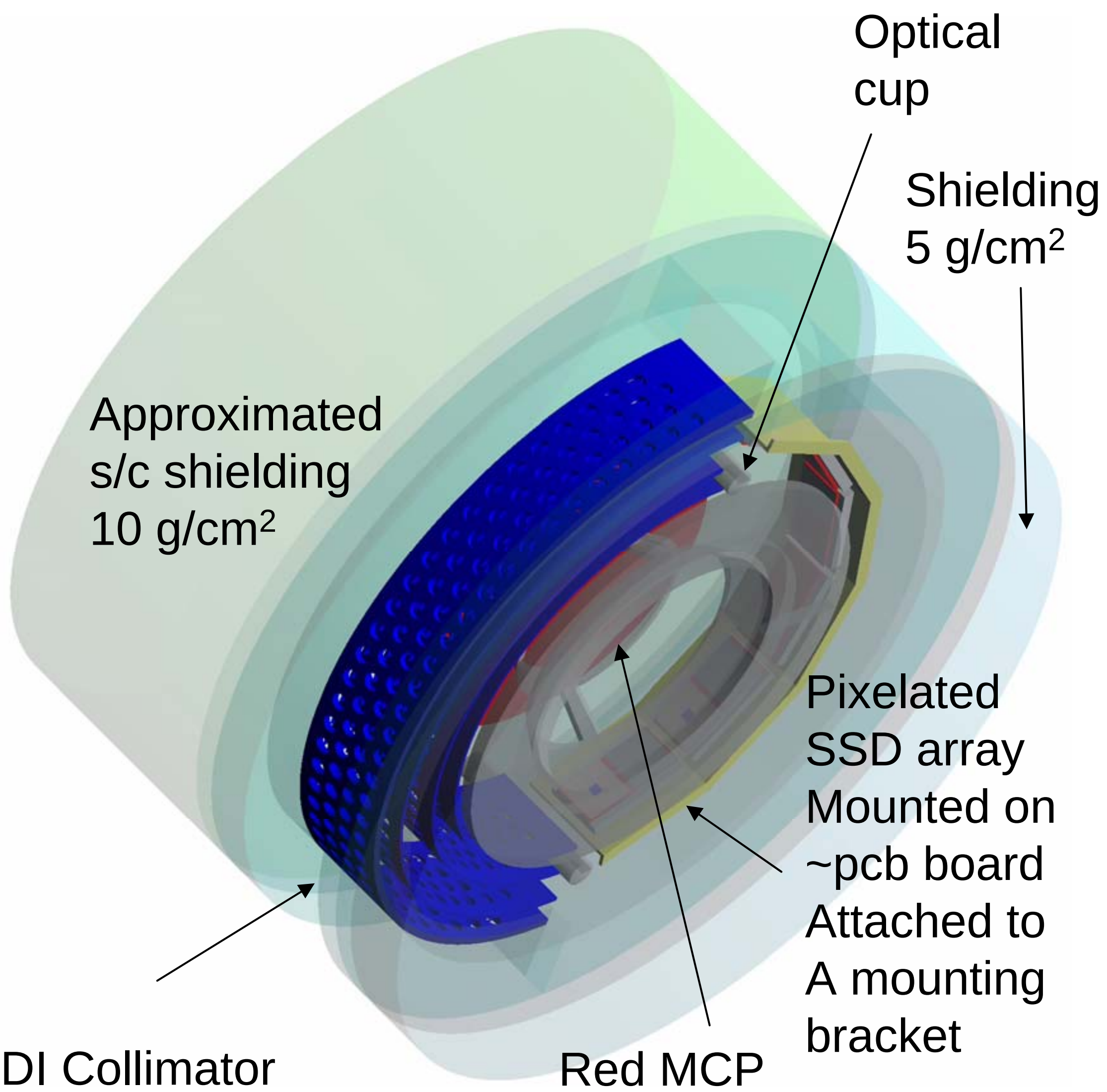


GEANT4 model of JEDI

Wireframe view with some shielding







Optical cup

Shielding 5 g/cm^2

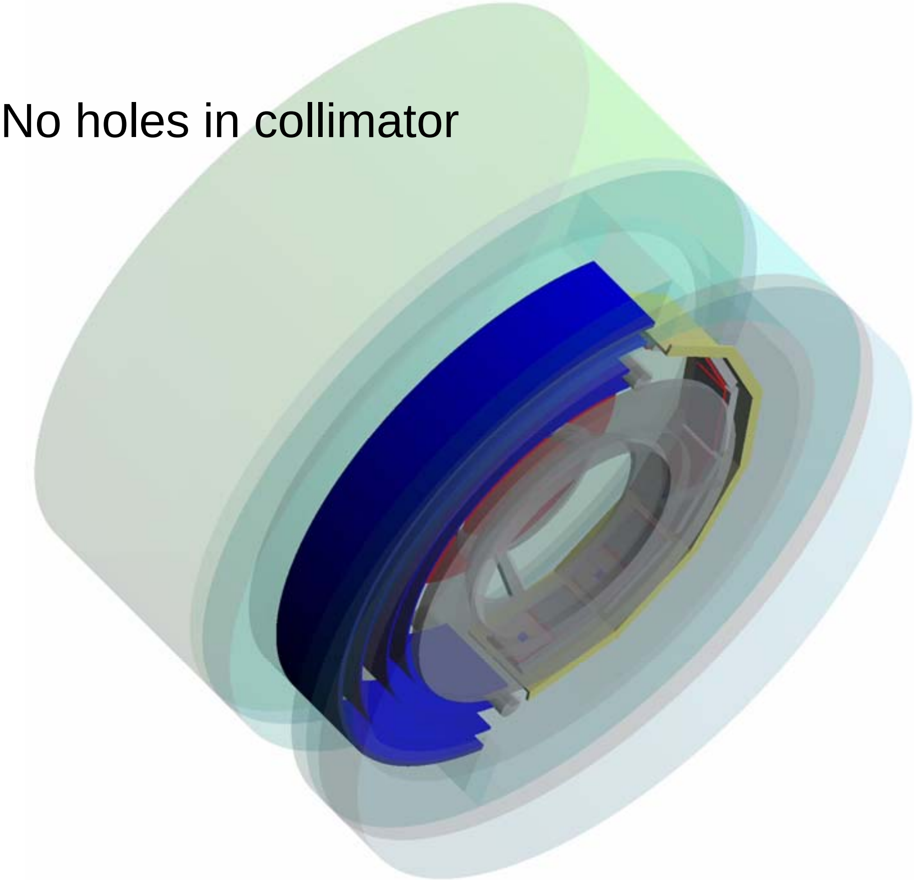
Approximated s/c shielding 10 g/cm^2

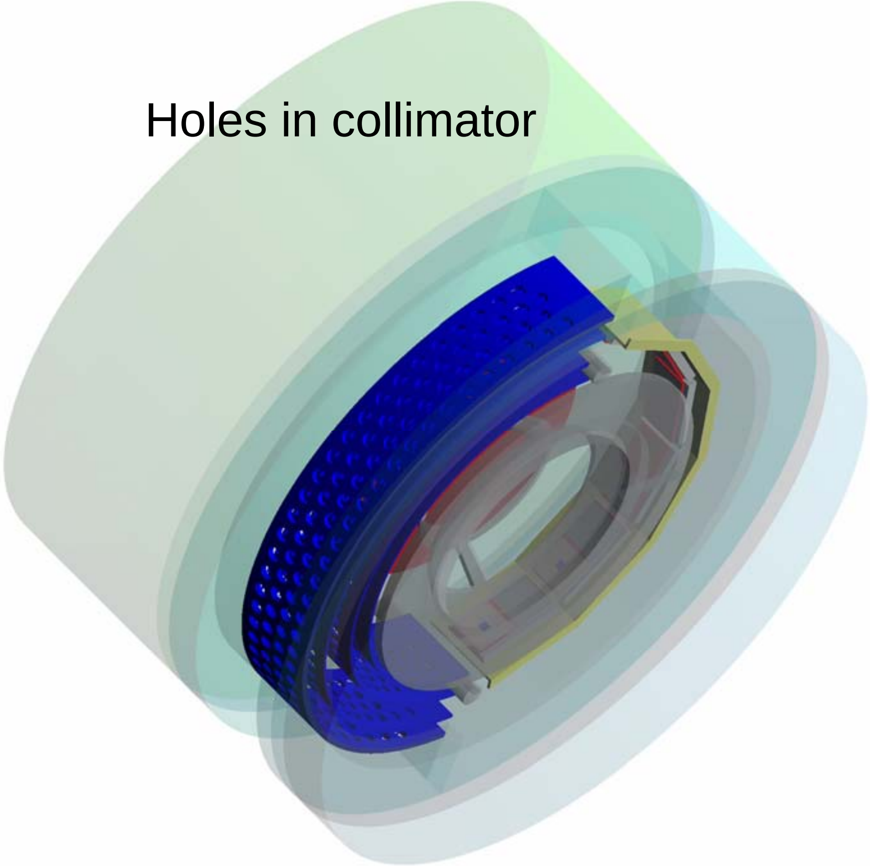
Pixelated SSD array Mounted on ~pcb board Attached to A mounting bracket

JEDI Collimator

Red MCP

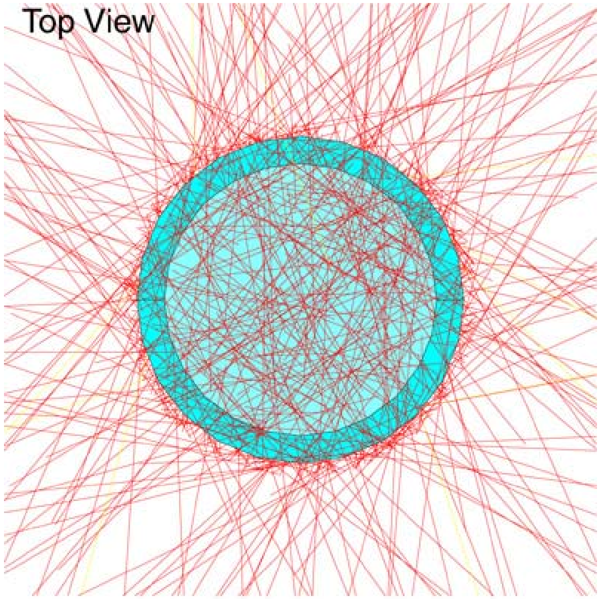
Background vs. foreground

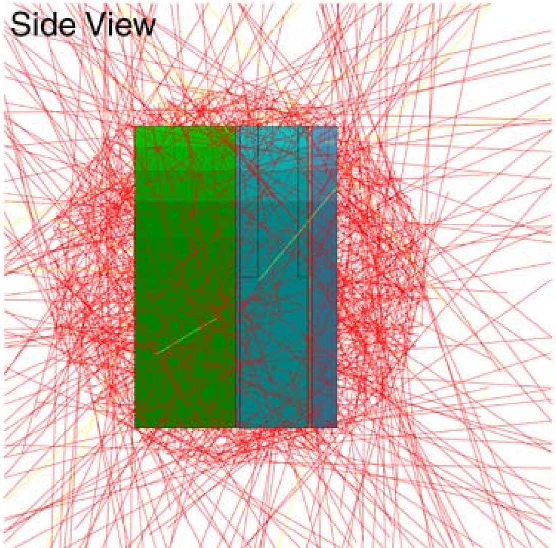

No holes in collimator


Holes in collimator

Technique: Create two identical models of the sensor: one with holes and the other without the holes. This is not exactly correct as secondary particles will be created by the material filling the holes that would not be there in the regular collimator. However as the distribution of secondary particles is ~ isotropic inside the sensor and the geometrical factor of the "holes" is small compared to the entire model this will be a very small effect.

GEANT4 runs



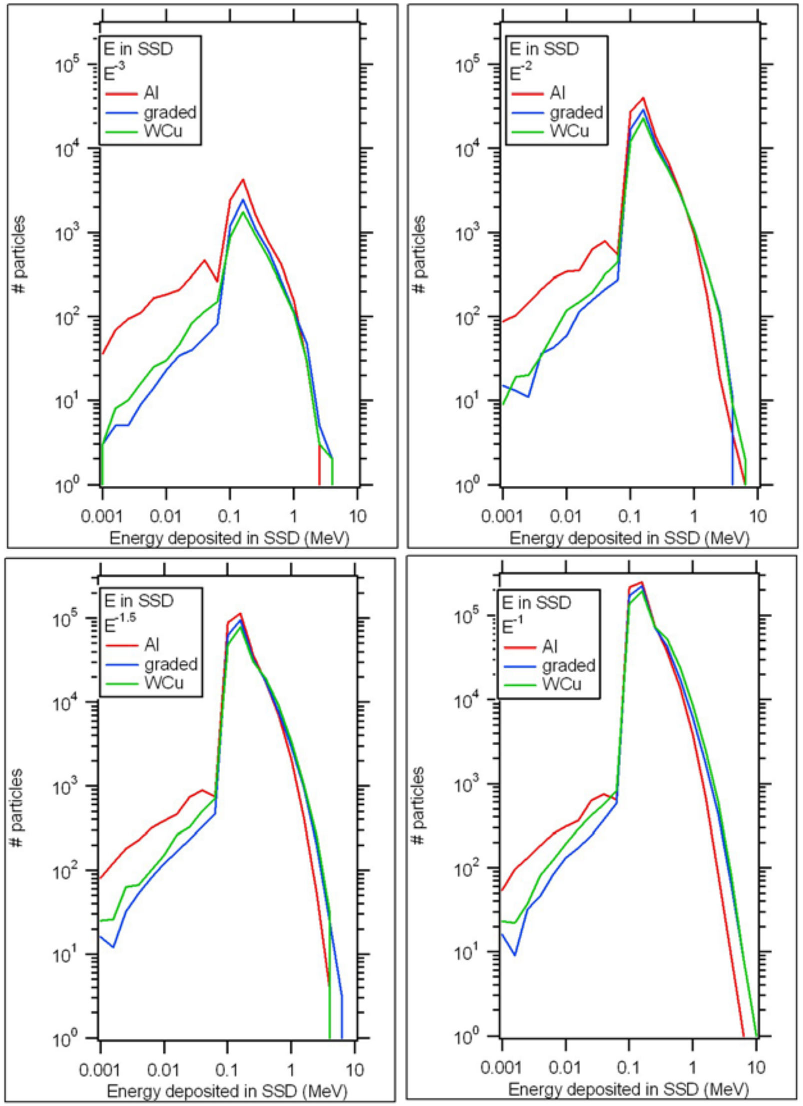


We then place the model inside of a spherical source surface just larger than the model. We distribute particle launch position randomly on the inner surface and launch that particle with a cosine angular distribution. This technique simulates an isotropic distribution inside of a spherical shell.

We will be able to identify the “background” rates from the model without the holes and then be able to do a background subtraction from the model with the holes to identify the real foreground rates, geometrical factor, etc…

We also ran two different implementations of the electromagnetic physics libraries available: The standard EM package, and the Low Energy EM package. The results obtained in the energy range of interest were nearly identical.

GEANT4 results

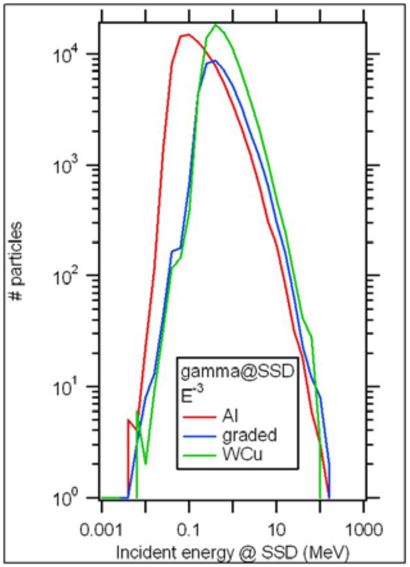


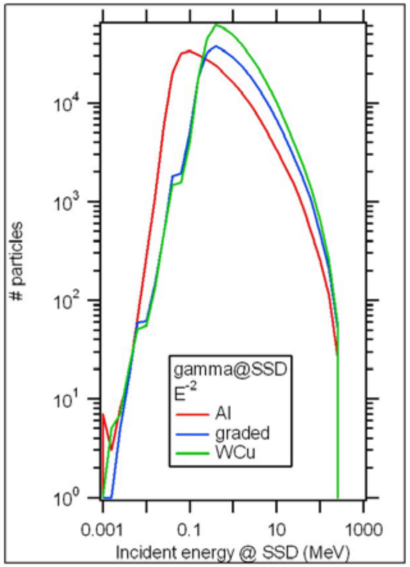
Total Energy deposition in the SSD.

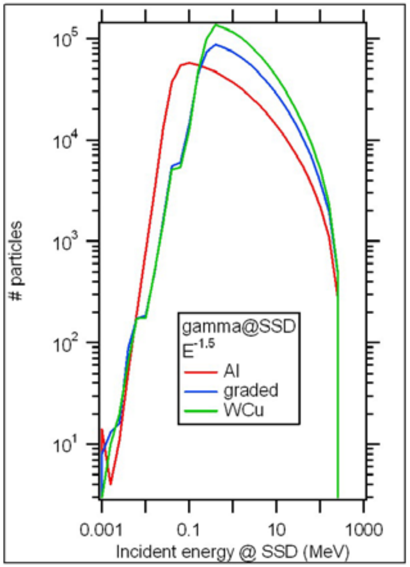
In this round of runs we were trying to find the optimal material to use as a shield. We have a fixed amount of mass, and were looking at a pure Al, a WCu, and a graded shield with Al on the outside and W on the inside.

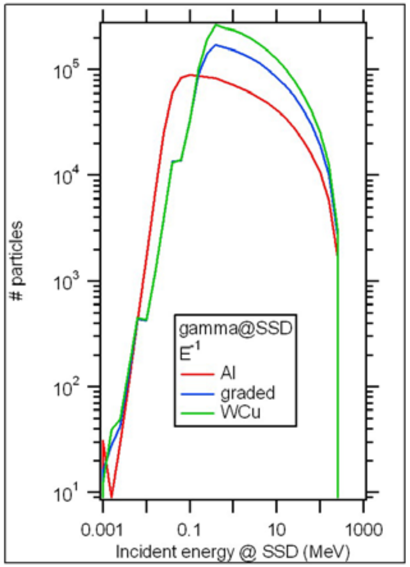
The results of the simulations indicate that the pure WCu shield is best for reducing the total energy deposition in the SSD. This total energy deposition includes that deposition from the primary penetrating electron and all secondary particle depositions.

GEANT4 results









Photons hitting the MCP

For this round we were concerned with the number of photons that hit and therefore may trigger an MCP response.

The spectrum of secondary photons hitting the MCP is shown here. The spectra is clearly very dependent on both the material used as the shield and the incident electron spectra.

Based on these simulations we decided that the differences in these spectra are unlikely to be a driver for the selection of the shield material.

Conclusions

Missions where we have used GEANT4

Future

- JUNO
- RBSP
- MMS
- BebiColombo
- Solar Orbiter
- NPOS

Current

- ACE
- Cassini
- Messenger
- New Horizons
- Ulysses

Past

- Galileo
- IMP8